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Vegetation History and Archaeobotany

Reconstruction of Middle Pleistocene palaeoenvironments based on pollen and stable isotope investigations at Val-de-Lans, Isère, France

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Abstract. In the Vercors uplands, south-west of Grenoble, the Val-de-Lans syncline is filled with thick lacustrine and glacio-lacustrine Pleistocene deposits. Artifacts discovered on its surface indicate an age older than the last glaciation. Pollen analytical investigations of five sediment sequences, including lake marls, has enabled the reconstruction of the interglacial vegetation cycle (La Côte Interglacial) which, taking into account the rôle played by *Abies* and a *Pterocarya* expansion towards the end of the interglacial, may be correlated with the Holsteinian Interglacial. At the site Lolette, this interglacial is followed by two short stadials which alternate with interstadials characterised by *Picea* forests. Oxygen isotope studies, including $\delta^{18}O$ investigations, provide additional evidence for climate changes during the interglacial.

Key words: France – Middle Pleistocene – Holsteinian – Pollen analysis – Oxygen isotope investigations

Introduction

Val-de-Lans is a 10-km-long, 2-km-wide syncline that runs NNE-SSW in the northern part of the Vercors Massif, west of the French Alps (Fig. 1). The flat bottom of this basin lies at about 1000 m altitude. The Val-de-Lans basin is drained mainly by the upper Bourne river which flows in the direction of the Basse-Isère. The Furon river crosses the northernmost part of the basin and flows directly into the Isère through the Engins Gorges.

In the western part of the basin, the Bourne river lies in a 20-30 m deep basin within a Pleistocene infilling that forms a terrace-like feature of fine lacustrine/palustre deposits (Pompillon formation). The basin is closed to the south by the steep glacio-fluvial cone (*cône* in French) of Villars-de-Lans which is partly covered by a local well-preserved moraine (Moraine des Pierres).

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In 1969, Malenfant found at the surface of the Pompillon formation several Levalloisian artefacts of a late Acheulean or archaic Mousterian age. Later, Monjuvent discovered sand layers with allochthonous crystalline blocks interbedded in the upper part of the Villars-de-Lans *cône*. This led Malenfant and Monjuvent (1978) to the following conclusions:

1. The Pompillon formation predates the last glaciation. The Lans valley was obstructed by a Riss glacier which would explain the presence of glacio-lacustrine sediment with allochthonous material observed in the Villars *Cône*.

2. The archaic prehistoric artefacts observed at the surface of the Pompillon formation suggest that the latter was not covered by the Isère glacier of Würmian age; it is assumed that neither this glacier, nor smaller local glaciers, reached the altitude of Val-de-Lans.

After the discovery of compressed peat layers at Pompillon by Monjuvent, several borings were undertaken between 1978 and 1987 in order to elucidate the stratigraphy of the Pompillon formation. The first results were described by Beaulieu and Monjuvent (1979, 1985). The present paper presents a tentative synthesis based mainly on unpublished pollen analyses from ten corings. The pollen sum ranges from 300-500 and 150-200 for sediments corresponding to temperate episodes and glacial periods, respectively. An average of 380 pollen has been counted per sample. The raw data may be consulted in the European Pollen Database or obtained from the author (J.-L. de Beaulieu).

Lithostratigraphy and palynostratigraphy

Stratigraphy based on corings at Pompillon

At the so-called Pompillon locality, the Pleistocene deposits form a bench sloping gently from 980 to 1040 m. At the contact with the present valley, this slope is incised over a horizontal distance of several metres. In this incision, the already mentioned compressed peat layers occur within a bed of sand and sandy silts.

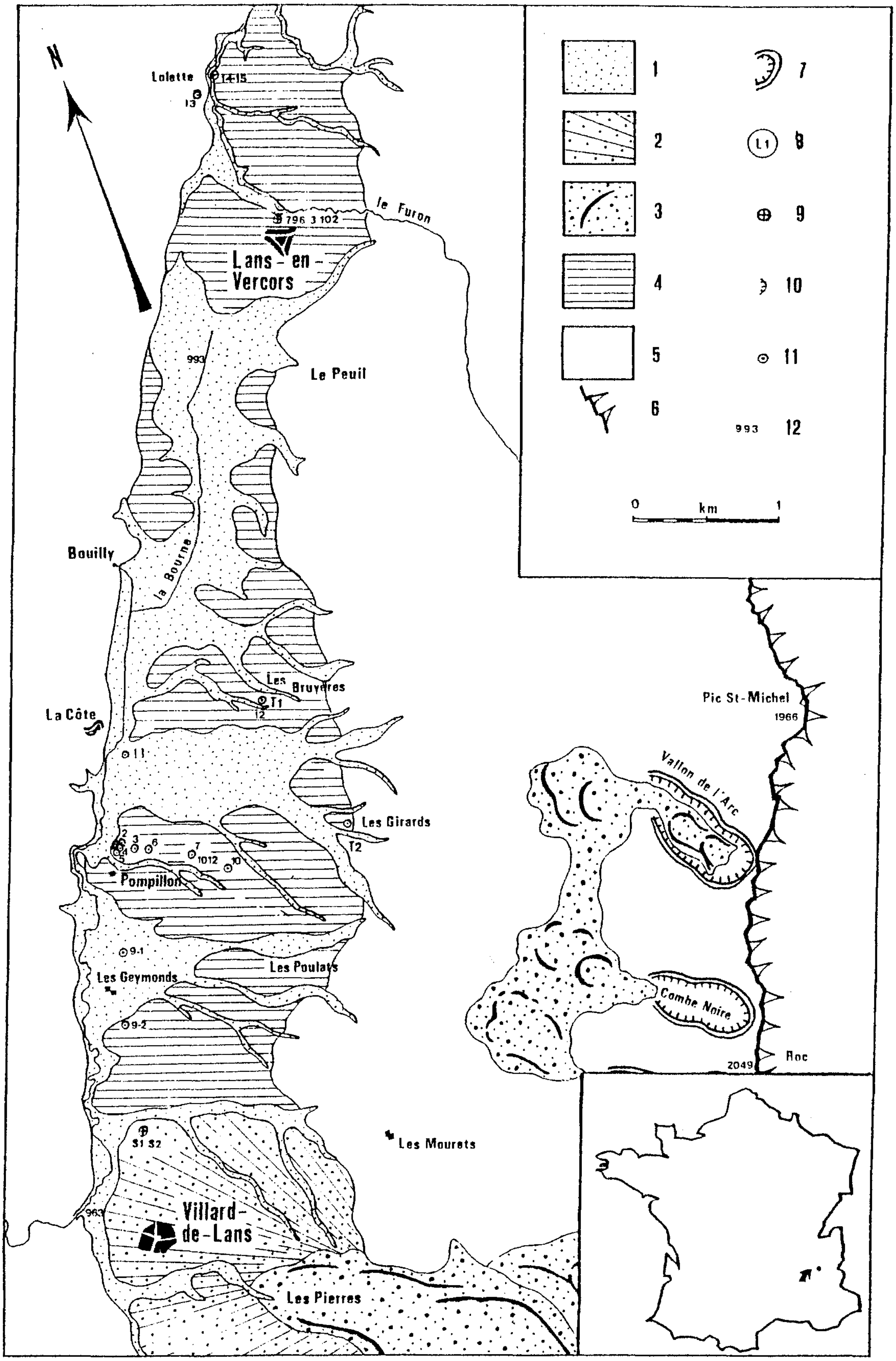

Fig. 1. Map of the study area showing the main geological features and the location of the sites investigated. *1*, alluvial deposits (Holocene); *2*, Villard-de-Lans cone (Würmian and ante-Würmian); *3*, local moraine (Würmian); *4*, Pompillon series (and Lans plateau); *5*, substratum and various surface deposits; *6*, eastern cliff (calcareous) of Vercors (subalpine border); *7*, glacial corrie; *8*, geographical profile; *9*, technical coring; *10*, Pompillon outcrop; *11*, location of corings discussed in text; *12*, altitude in metres

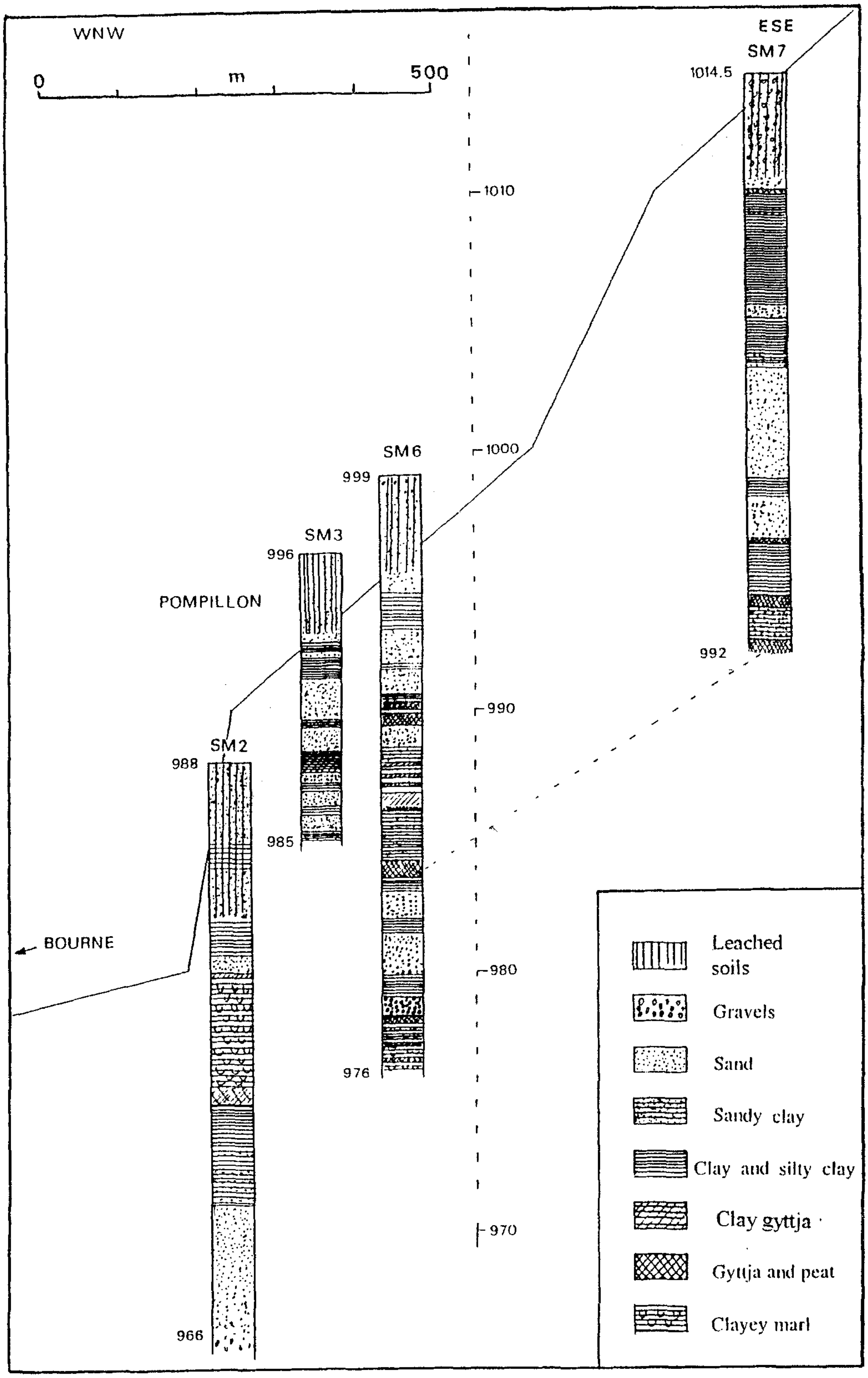

Fig. 2. Lithology in cores along a transect on the Pompillon slope

A transect of several corings was made with a view to defining the stratigraphy of the Pompillon formation as a whole (a maximum depth of 20 m was only possible with the available coring equipment). The lithological sequences obtained are summarized in Fig. 2.

The pollen diagram derived from core SM2 (Beaulieu and Monjuvent 1979) displays, above stadial spectra (zone A), spectra suggesting an interglacial forest phase (zones B and D) interrupted by a cold phase (zone C). However, the more detailed pollen diagram derived from core SM5 (Fig. 3) reveals clear interglacial dynamics characterized by a simultaneous expansion of *Abies* and *Taxus*, followed by a phase with dominant *Abies* (and abundant *Buxus*), and lastly a phase with *Fagus* and *Abies*, a few *Pterocarya* and slightly increased *Pinus*. This pollen zone is abruptly interrupted by a thick gravel layer underlying fine deposits. This is a lateral equivalent of core SM1.

Figure 4 summarizes the pollen data derived from cores at various points along the transect (SM2, SM3, SM5, SM6 and SM7). The nature of the sediments and their poor pollen content, except at certain levels, indicate that they correspond to stadial deposits. Within these deposits, more organic levels are identifiable that reflect interstadial episodes.

Correlation of the pollen zones in the profiles from the various corings suggest that there was a dip of about 2% during lake infilling which is consistent with the present day slope of the plateau (Fig. 5).

La Côte (SM11) and Les Bruyères (SM12)

The coring at La Côte, about 2 km to the north of the Pompillon section, provided an interglacial sequence equivalent to that described in SM5, although more complete (Beaulieu and Monjuvent 1985; Fig. 6). In this core, pollen zones characteristic of pioneer forest phases (zones SM11 1-5) and three late-temperate Interglacial zones are recorded for the first time. This sequence was called 'Interglaciaire de la Côte' after the local placename. Of particular interest is zone SM11 15 where *Pterocarya* is well represented.

This interglacial sequence is interrupted at approximately mid way (just after the expansion of *Fagus*) by sterile blue clays and silts that contain a cold stadial pollen flora. These minerogenic sediments are due either to a massive erosion of older stadial sediments or to the occurrence of a cold episode that subdivides the interglacial.

Core SM12, from the Les Bruyères site, provided an Interglacial sequence interrupted by grey-bluish clays before the *Fagus* expansion (Fig. 7). At the top, where the sediments are extremely poor in pollen, a spectrum has been recorded that resembles the pollen assemblage with *Abies, Fagus* and *Pinus* recorded in Zone SM11 14 (see Fig. 6). The grey-bluish clays are probably contemporaneous with those described at La Côte, but the underlying marls are older than at La Côte since *Fagus* has not yet attained high percentages. This indicates that the bluish clays were deposited unconformably, probably as a result of a gully erosion in the interglacial marls.

Furon and Lolette

Sediments corresponding to the Pompillon formation have also been detected in the Furon basin, about 2 km to the north of the Lans en Vercors pass. Two borings (SM14 and SM15) were made on the eastern side of the river near the village of Lolette.

The pollen sequence (Fig. 8) shows the same characteristics as the La Côte Interglacial, but the *Taxus* phase is absent probably because of a hiatus, and the zones with dominant *Abies* (zones SM14/15-4 and 6) are interrupted by an argillaceous layer that yielded spectra rich in *Pinus* and herbs (zone 5). In the overlying continuous marly sediment, a series of phases is recorded in which *Abies*, *Abies* and *Fagus*, and *Abies* and *Fagus* with *Pterocarya* successively dominate without any indication of an intermediate cold episode.

This set of observations shows that the argillaceous layers interrupt different episodes of the same interglacial period and are probably due to erratic floods with high sediment load that occurred at various times in different places within the extensive palaeolake of Val-de-Lans. They are therefore of no climatic significance. The La Côte Interglacial was most likely characterized by continuous forest dynamics with no sudden regressive episodes.

A few hundred metres away from the last mentioned corings, to the south of the small village of Lolette, marly deposits outcrop on the margin of the National road. These deposits are unconformably overlain by thick blue clays. A coring was made below this section (SM13) which went through 6.20 m of marl and more or less sandy silt, followed by 5 m of blue-greyish clays and finally reached a pebble layer (Fig. 9). Pollen was not recorded below 6.67 m. The pollen diagram therefore corresponds to the upper part of the profile. This diagram bears a close resemblance to the preceding. The first pollen zones (SM13 1-5) correspond to the beginning of the La Côte Interglacial. There is no pollen assemblage with dominant *Fagus* and *Abies* nor is there a *Pterocarya* phase. Zone 6 resembles zone 17 at La Côte. Zone 7 may correspond with the beginning of a stadial characterized by a decline of *Picea* and an increase in herbs. Zone 8, marked by the reappearance of *Abies*, indicates sediment reworking at the beginning of a stadial or a short climate amelioration. Zone 9, with arboreal pollen percentages lower than 50%, may correspond to a stadial. Zones 10 to 13 reflect a new temperate cycle which is here referred to as Lolette 1 Interstadial.

Considering that the Lolette coring is situated 20 metres higher than that at Furon, where the La Côte Interglacial is well characterized, two hypotheses can be put forward, namely that the whole series represents a different time period or that the Pleistocene lacustrine layers slant abruptly from Lolette to Furon following the dip of the substratum. In the second case, the bottom of the Lolette sequence would correspond to the La Côte Interglacial sequence which is truncated between zones 5 and 6. The sedimentary sequence being almost continuous from that onwards, the upper part of the diagram should indicate botanical events that were subsequent to the La Côte Interglacial. These events are not recorded in the other corings because the sediment corresponding to the end of that interglacial was probably destroyed in an erosion episode. In view of the respective situations of the Furon and the Lolette corings and the short distance between the two cores, this is regarded as the more acceptable hypothesis.

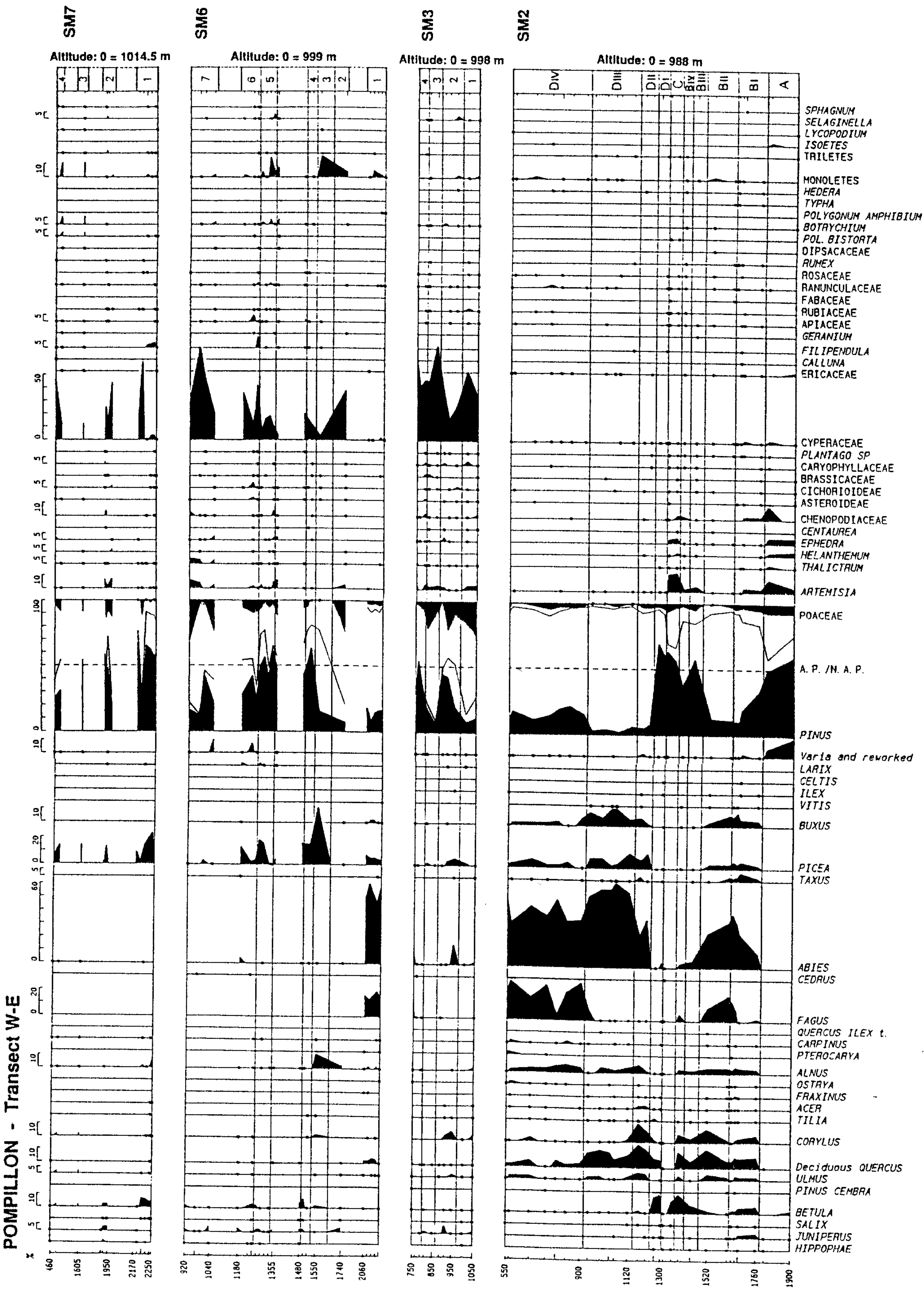

Fig. 3. Percentage pollen profile SM5

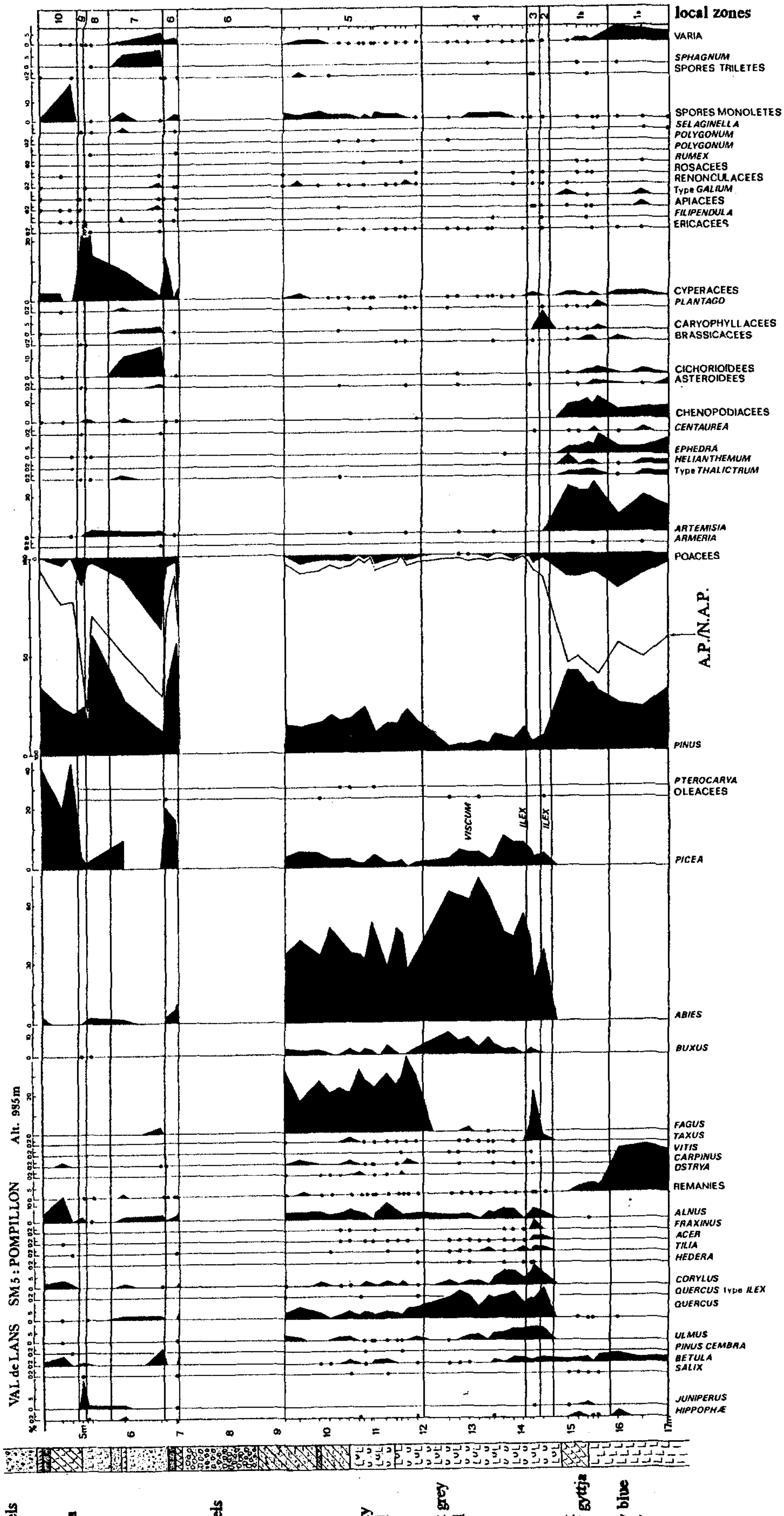

Fig. 4. Percentage pollen profiles from corings taken along a transect on the Pompillon slope

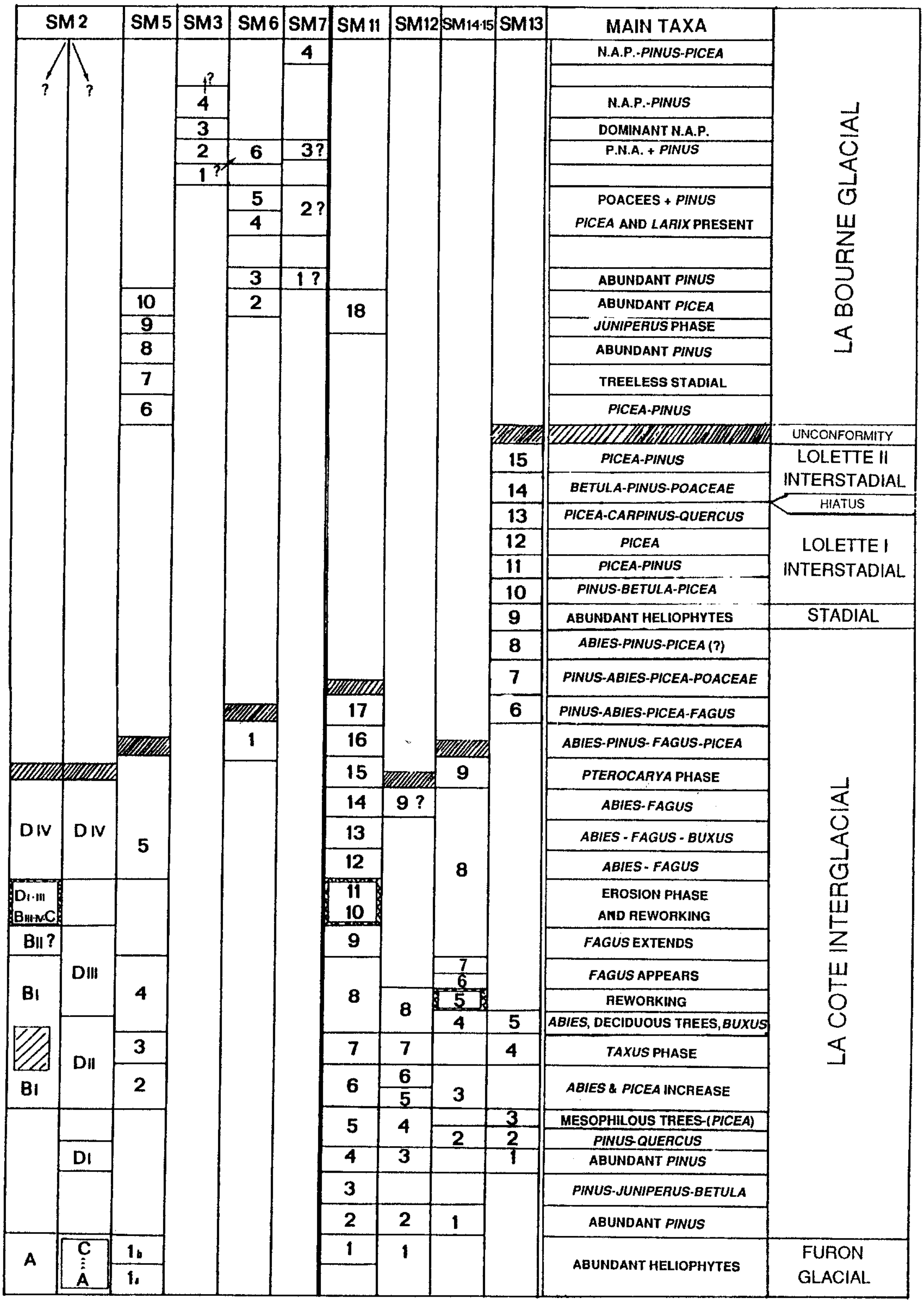

Fig. 5. Proposed correlation of the pollen zones from the various Val-de-Lans profiles

Discussion

On the basis of the evaluation of the pollen data (see above) a correlation scheme for the various profiles is proposed in Fig. 5. The following are the main overall conclusions that follow from the proposed correlations:

1. The bottom of each core consists of grey and blue clays corresponding to a glacial climate. The underlying coarser material (pebbles) could not be penetrated and so this substratum was not investigated. Geophysical investigations, however, suggest a much thicker Pleistocene infilling than was revealed by the corings (cf. Beaulieu

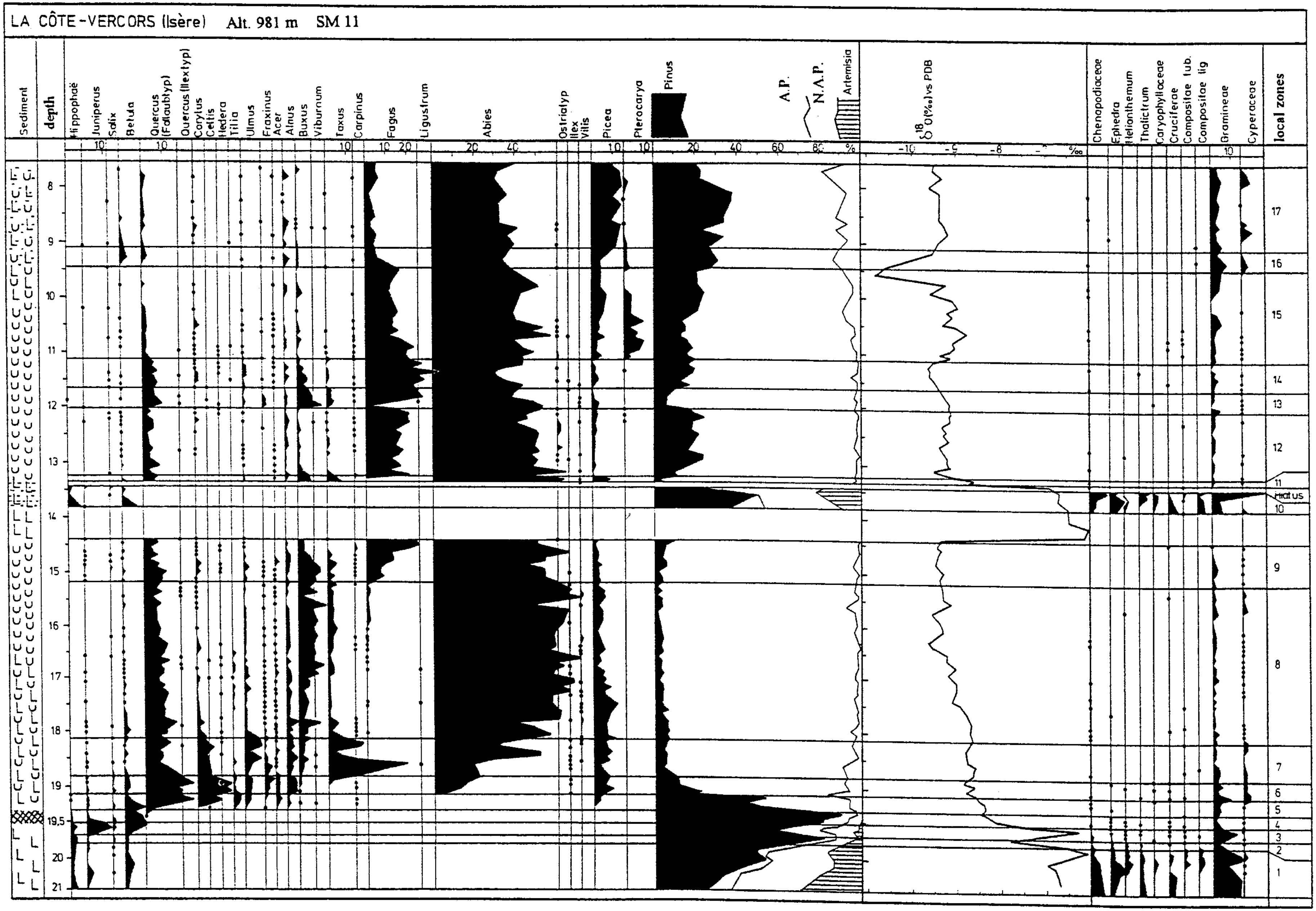

Fig. 6. La Cote pollen profile (SM11) and the ^{18}O curve

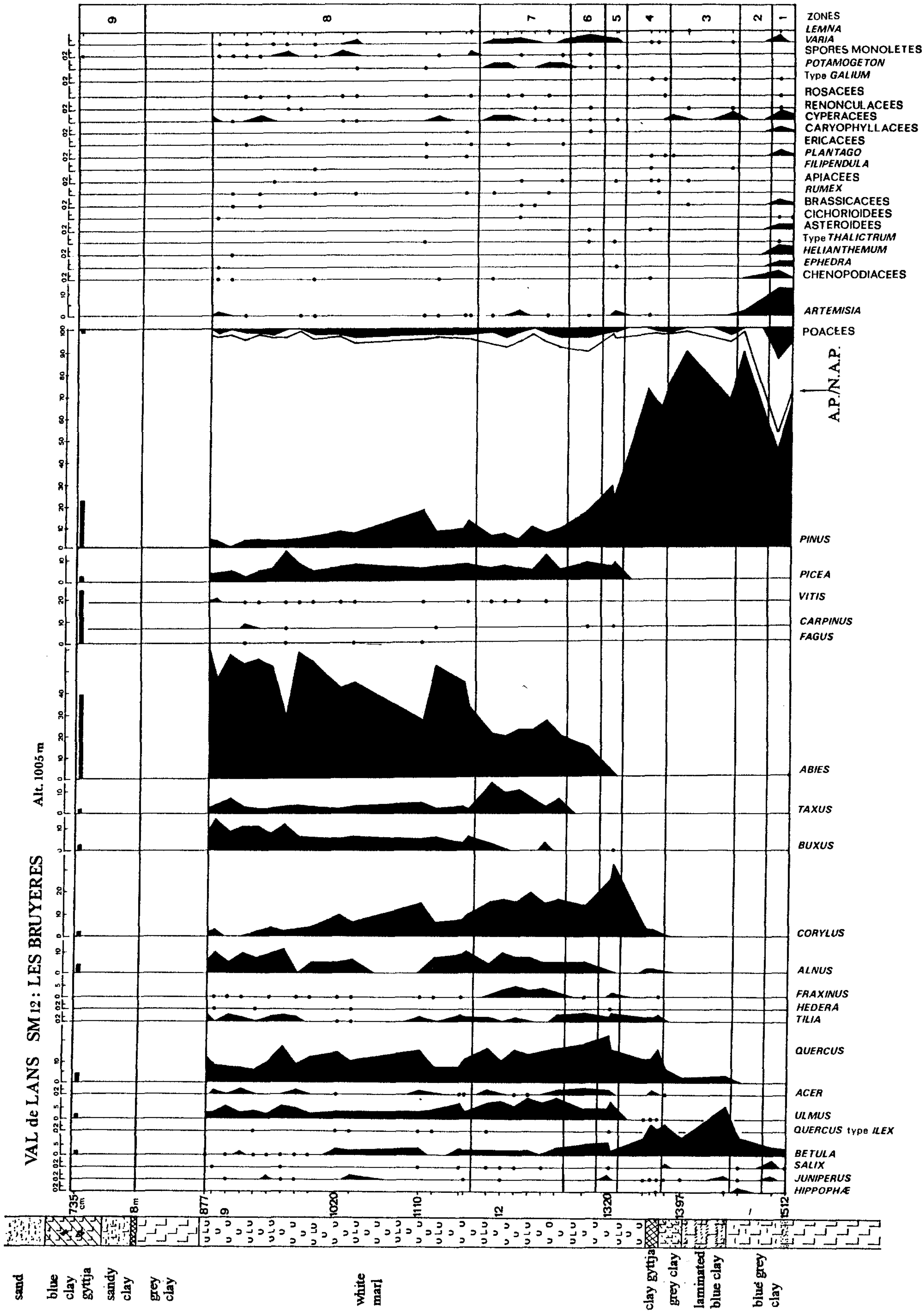

Fig. 7. Percentage pollen profile SM5 (Les Bruyères)

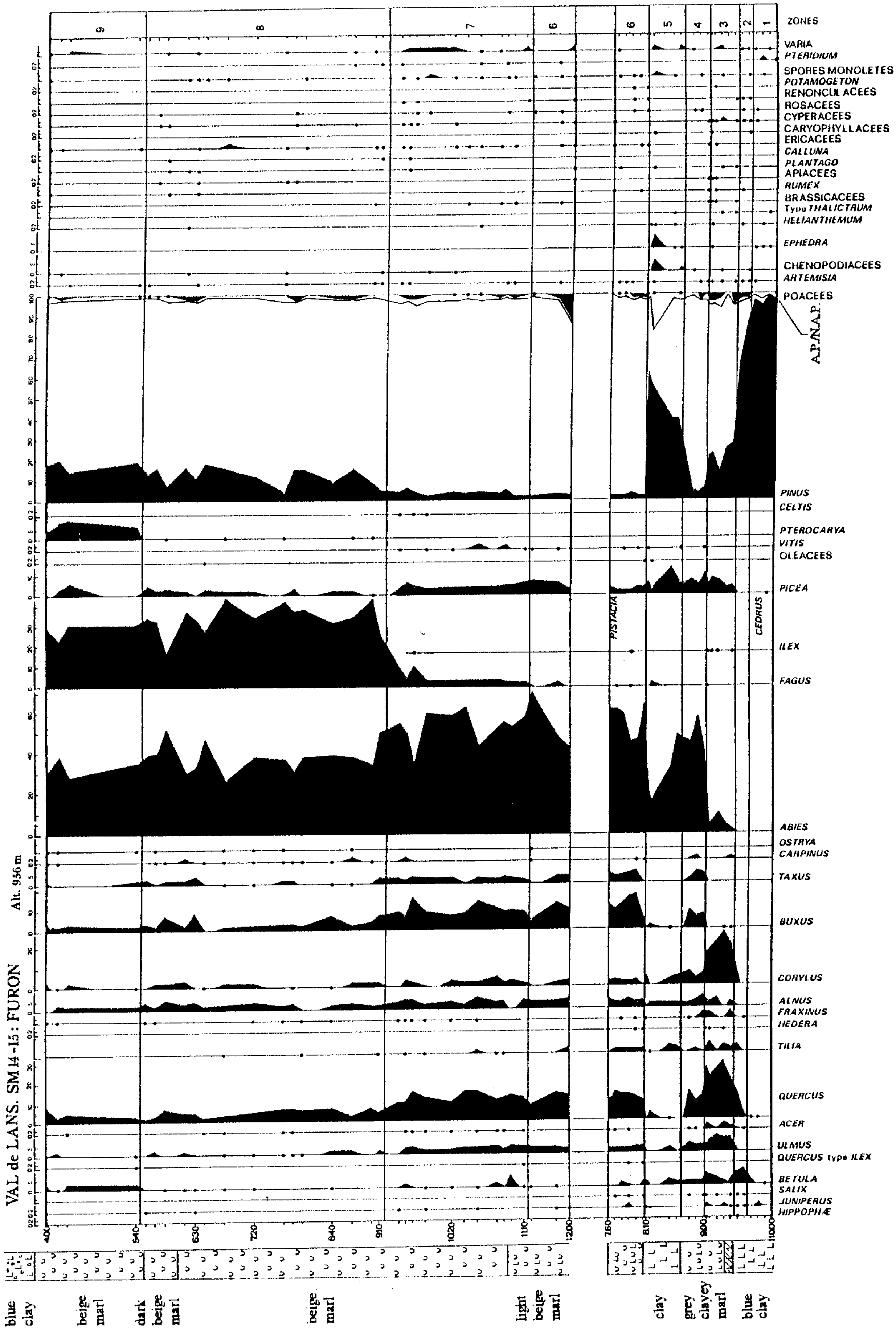

Fig. 8. Percentage pollen profile SM14/15 (Furon)

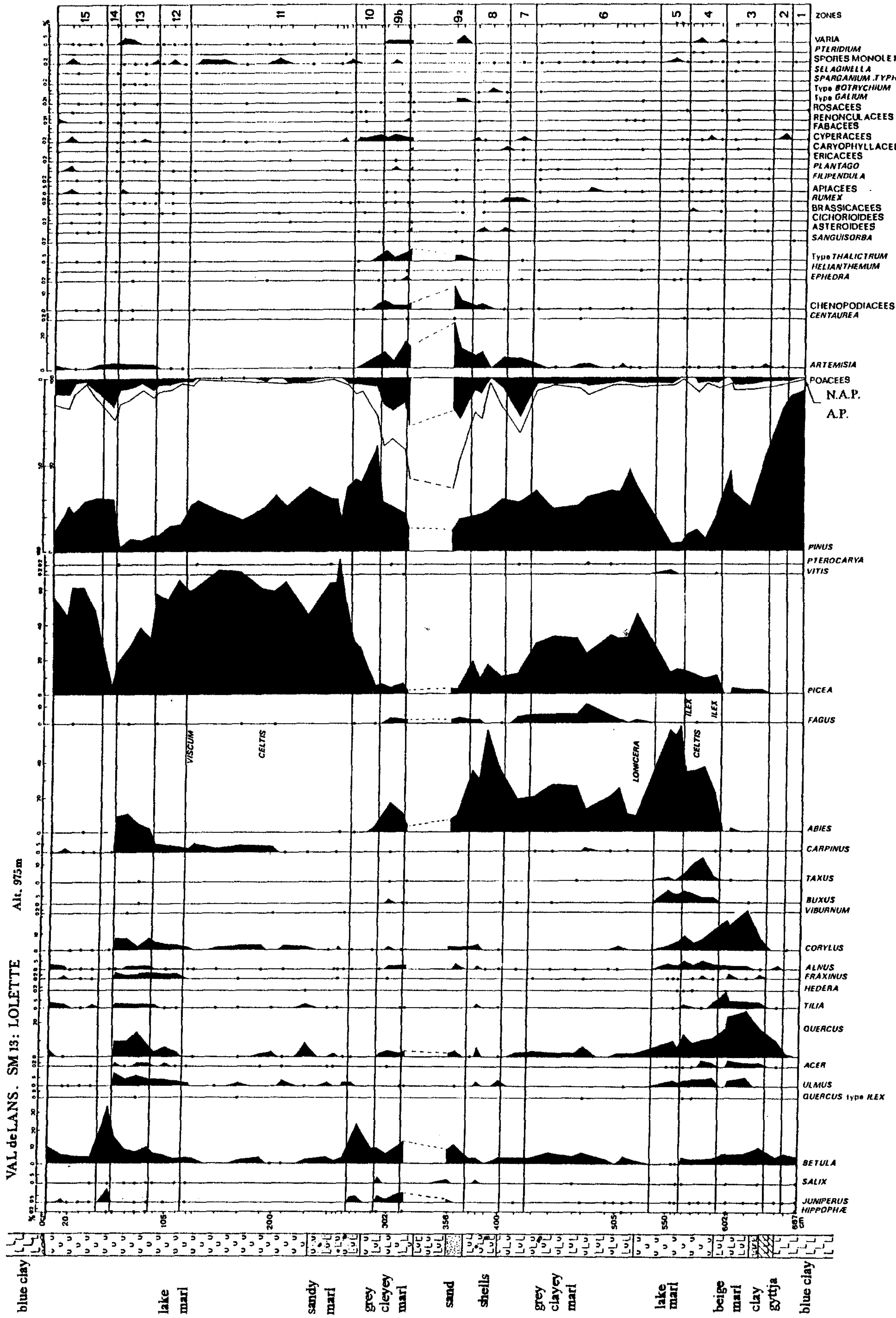

Fig. 9. Percentage pollen profile SM13 (Lolette)

and Monjuvent 1985). This lower part is referred to as the Furon Glacial.

The passage from clays to biogenic carbonated sediments that characterizes the onset of the La Côte Interglacial reflects a major change in the evolution of the palaeolake. That a major change did take place is consistent with the present geomorphology which includes features such as a sub-horizontal channel that runs to the west of the syncline, a steep slope to the west and a very gradual slope to the east. There is no information available regarding the shores of the palaeolake, and thus the bathymetry of the palaeolake remains unknown.

2. The episodes which resulted in argillaceous sediments including a 'cold' pollen flora that interrupt the marly sediments of the La Côte Interglacial have no stratigraphical significance. These reflect local sediment transport, probably in the context of torrential floods, and hence should not be given undue weight in the reconstruction of vegetation and climate history of the region.

3. The lake marl sediments are truncated by a pronounced erosion phase. Only core SM13 seems to show a succession of two short cold episodes and two temperate episodes (Lolette I and II) just after the interglacial. Because of this truncation, no clear relationships can be established between the interglacial and stadial deposits (La Bourne Glacial) in the upper part of the Pompillon sequence.

Vegetation history

The correlations proposed in Fig. 5, which take into account the lithostratigraphical data (see above), are now used as a basis for the description of the vegetation history.

1. *Pleniglacial phase with dominant herbs: the Furon Glacial (SM1-A, SM5-1a and 1b, SM11-1 and SM12-1).* Above the pollen-deficient clays, the two first polliniferous levels yielded spectra closely resembling those from the Oldest Dryas in the region. They are characterized by the dominance of heliophytes (steppic) herbs, *Artemisia*, Chenopodiaceae and particularly *Ephedra*, evidence for the regional occurrence of *Hippophae* and probably *Pinus* too. No evidence is found for a forest vegetation on the Lans plateau. In SM5 1a, at the base of the clay layer, great amounts of more or less corroded pre-Quaternary palynomorphs were recorded.

2. *Phase with* Pinus *dominant (SM11-2, 3 and 4, SM12-2, SM13-1 and SM14/15-1).* SM11 (La Côte; Fig. 6) revealed the most complete late-glacial vegetation dynamics: an early *Pinus* maximum (probably not from local origin) is followed by a short episode with *Juniperus* (probably a pioneer shrub on the plateau). Thereafter, the *Betula* curve rises and *Pinus* peaks for the second time. This indicates the establishment of a conifer forest in the surroundings of the lake. The first deciduous trees are also recorded. At the other sites, there is no distinct *Juniperus* phase.

3. *Spread of mesic trees with abundant* Pinus *(SM11-5 p.p., SM12-4, SM13-2 and SM14/15-2).* The *Pinus* vegetation types continue to develop, and mesic trees begin to expand in the region (*Quercus* first, followed by *Tilia*, *Ulmus* and *Corylus*).

4. *Major expansion of deciduous trees.* Spread of *Abies* and *Picea* (SM5-2, SM11-6, SM12-5 and 6 and SM14/15-3) is recorded and a mixed forest with abundant *Corylus* established itself on the plateau. These forests were species-rich, as suggested by pollen records for *Ilex*, *Hedera* and *Carpinus*. Meanwhile, *Picea* and *Abies* began to expand. At the site, the vegetation appears to be intermediate between lowland and mountain type.

5. *Phase of* Taxus *expansion (SM5.3, SM11.7, SM12.7, SM13.4).* *Abies* was hindered in its expansion by a strong development of *Taxus*; later these two trees probably formed a mixed forest. During this phase *Vitis* pollen is recorded for the first time, and the *Buxus* curve is initiated. The establishment of *Abies* is not related to a fall in temperature but rather to more favourable moisture conditions as was the case in the French Southern Alps during the Atlantic period.

6. *Phase with dominant* Abies *(SM5-4, SM11-8, SM12-8 and SM14/15-4, 5 and 6).* The *Taxus* increase was of short duration and *Abies* was soon the main, if not the only, tree in Val-de-Lans, the other AP records probably reflecting regional and long-distance transported pollen. However, the rise in the *Buxus* pollen percentages and regular pollen occurrences of *Rumex*, Apiaceae, Ericaceae and Rosaceae show that the forest was varied and not completely closed. It is during that episode that *Fagus* pollen is recorded for the first time.

7. *Dominance of* Abies *and continuous curve of* Fagus *(SM11-8b and SM14/15-7).* The situation is the same as in the preceding phase, but the continuous *Fagus* curve indicates the establishment of beech near the site.

8. *Expansion of* Fagus *(SM11-9).* SM5-5 and SM14/15-8 show a sudden rise in the *Fagus* curve. In SM11-9 the expansion phase is represented by 60 cm of sediment. The *Fagus* expansion was mainly at the expense of *Buxus* and *Quercus* which suggests that the *Fagus* and *Abies* forest encroached upon the domain of the oak forest at lower altitude. The decline in *Picea* at this time is more difficult to explain.

9. *Dominance of the* Fagus *and* Abies *forest (SM5-5, SM11-12, 13 and 14, SM12-9? and SM14/15-8).* Apart from the overall dominance of *Abies* and *Fagus*, these zones are characterized by an increase in *Pinus*. The transitory expansion of *Buxus*, *Quercus* and *Taxus*, well marked in SM11-13 and 14, is also recorded in SM14/15, though less markedly (at c. 6 m). There are notable differences between the relative frequencies of *Fagus*, *Abies* and *Pinus* in the two corings. This may be due either to differences in the transportation and deposition of

pollen types or to an irregular distribution of these taxa around the lake. During this phase the first pollen grains of *Pterocarya* are recorded.

10. *Spread of* Pterocarya *(SM11-15, SM14/15-9).* Apart from the spread of *Pterocarya*, which has representation in the range 5-10%, there appears to be no changes in vegetation. It may be assumed that *Pterocarya* played an important role in the general proximity of the ancient lake.

11. *Expansion of* Pinus *and* Picea *(SM11-16 and 17, and SM13-6 and 7).* The expansion of these two taxa, which coincides with an episode of very low pollen percentages for the thermophilous deciduous trees notably *Pterocarya*, is a characteristic feature of post-temperate dynamics. A slight increase in the Poaceae percentages also suggests an opening of the surrounding forests.

12. *Stadial with abundant heliophytes (SM13-9).* All the sequences, except SM13 (Lolette), are truncated above the upper part of the post-temperate phase. SM13-9 corresponds to a stadial with an heliophilous non-arboreal vegetation.

13. *Phase with dominant* Picea, *i.e. Lolette I Interstadial (SM13-11 and 12).* After a transition phase with abundant heliophilous pioneer trees (*Betula*, *Pinus* and *Juniperus*; cf. SM13-10), *Picea* was the dominant tree around the site and *Pinus* was also present. Zone SM13-12 is characterized by a *Pinus* decline coinciding with continuous curves for several mesophilous trees (*Ulmus, Quercus, Fraxinus, Corylus* and *Carpinus*), which suggests a regional expansion of these trees.

14. *Phase with* Picea *and mesophilous trees (SM13-13).* At the end of the Lolette I Interstadial, higher pollen values of mesophilous species denote the arrival of these trees near the site. The expansion of deciduous trees at the expense of *Picea* is quite unusual, as mesophilous trees generally occur during an early temperate phase prior to the expansion of conifers, e.g. *Abies* and *Picea*. Soil evolution may be evoked to explain these classical dynamics (Zagwijn 1972). In zone SM13-13, *Carpinus* pollen is more abundant than in the La Côte Interglacial. Re-bedding from a lower level may therefore be excluded. On the other hand, the expansion of mesophilous trees in a zone characterized by a slight decrease of the NAP (Poaceae and *Artemisia*) would suggest that the pollen may be derived from various sources. As no equivalent to this pollen zone has been recorded in other sequences from that site, a definitive interpretation is not possible.

15. *Phase with* Betula, Pinus and Juniperus *(SM13-14 and SM13-14).* After a sudden fall in the curves of mesophilous trees, which suggests a hiatus, the unusual spectrum which constitutes zone SM13-14 indicates an open landscape with stands of heliophilous trees.

16. *Second phase with dominant* Picea, *i.e. Lolette II Interstadial.* The upper pollen zone of the Lolette sequence is characterized by a second expansion of a *Picea*-dominated forest. At the top of this zone lake marls are in discordant contact with sterile blue clays.

The sediment sequences recorded at Pompillon above the La Côte Interglacial (SM3, SM6 and SM7) cannot be correlated with the upper part of the Lolette sequence. The few organic layers containing pollen are interbedded in pollen deficient clays and silts and are either slightly younger or much younger than the Lolette sequence. Apart from pollen zone SM6.2, which indicated a *Picea*-dominated forest, the spectra are characterized by a dominance of *Pinus* and frequently with *Picea* as an important component. *Larix*, too, is present. *Picea* and abundant heliophytes (cf. *Artemisia, Ephedra,* and Chenopodiaceae) suggest a markedly open landscape such as exists today at the upper subalpine belt (but not in zones SM6-2 and SM7-1). Abundant Cyperaceae indicate a very shallow lake.

The stable isotope ($\delta^{18}O$ and $\delta^{13}C$) record

The oxygen isotope ratio, i.e. the $^{18}O/^{16}O$ ratio or $\delta^{18}O$ values, in rainfall varies almost in parallel with the air temperature. This is due to the fact that in precipitation, the isotopically heavier water molecule ($H_2{}^{18}O$) rains out more readily than the lighter molecule ($H_2{}^{16}O$) (isotope fractionation). With lower temperatures and consequently increased differential loss of $H_2{}^{18}O$, ^{18}O in the steam of the air mass, and hence in the rainfall, gradually decreases. The isotopic variations in meteoric precipitation are transferred to groundwater and then to the water of lakes. In authigenic carbonate lake sediments (lake marl or *Seekreide*), by a second step reaction, the record of ^{18}O concentration in lake water is finally preserved. Lake marl is mainly formed during photosynthetic activities of submerged aquatic plants which use dissolved CO_2. The consequence is a CO_2 deficit, so that bicarbonate is decomposed into CO_2 and insoluble carbonate which precipitates. Thus, authigenic freshwater marl sediments, through their $^{18}O/^{16}O$ ratio, can provide information about temperature (Siegenthaler and Eicher 1986).

The carbon isotope ratio in authigenic lake carbonate, i.e. the $^{13}C/^{12}C$ ratio or $\delta^{13}C$ values, depends on factors rather different from those determining the $^{18}O/^{16}O$ ratio. In comparison with $\delta^{18}O$ values, which largely reflect regional climate change, ^{13}C may reflect at best local climatic conditions. However, ^{13}C variations do not indicate primarily climate-induced events.

In groundwater and river water, ^{13}C values generally range between -10 and -15‰. In lake water, the ^{13}C concentration of the CO_2-bicarbonate system is influenced by different factors but, at final equilibration with atmospheric CO_2, the $\delta^{13}C$ value is ca. 2‰. Biological activity of aquatic plants, which preferentially withdraw ^{13}C-depleted carbon, involves a ^{13}C enrichment in the dissolved bicarbonate. This magnitude of the effect depends on the productivity of the submersed plants. In some cases, the

^{13}C curve behaves similarly to the ^{18}O curve; this may be related to varying bio-productivity during warm and cold climate periods. Under certain conditions, therefore, the $\delta^{13}C$ curve may be regarded as an indicator of bioproductivity (Siegenthaler and Eicher 1986).

A study of ^{18}O and ^{13}C variations has been carried out on different cores from Val-de-Lans, the reference core being La Côte. The results from this core are presented in Fig. 10. Unfortunately, the isotope profile does not record the temperature rise at the glacial/interglacial transition. The relatively high $\delta^{18}O$ values below 19 m depth are the result of inwashed detrital sediments. Note also that the carbonate content in this part of the profile is relatively low (c. 20%). Between 19 and 14.4 m, the $\delta^{18}O$ values show only small variations that cannot be interpreted on the basis of comparison with the pollen profile. The high carbonate content (>80%) suggests interglacial conditions. In the upper part of the profile the curve declines by about 0.8‰. This decrease may not reflect a drop in temperature. It might be the result of a decrease in ^{18}O in the ocean, caused by isotopic light meltwater from the polar ice caps.

clearly points to detrital allochthonous sediments. As abruptly as started, the event comes to an end at 13.4 m when $\delta^{18}O$ values are similar to before and the carbonate content increases again to more than 80%.

In the upper part of the profile (between 13.3 and 7.5 m) the $\delta^{18}O$ curve shows substantial variations. After a small negative fluctuation (between 12 and 11 m), there is a trend towards increasing values (between 11 and 9.6 m) which corresponds with the occurrence of *Pterocarya* in the pollen profile. Both the $\delta^{18}O$ and pollen records, therefore, suggest higher temperatures. The decline in $\delta^{18}O$ values, which is recorded in this part of the profile, is restricted to a short segment (9.6-9.2 m). In comparison with the preceding positive fluctuation, $\delta^{18}O$ decreases by about 2‰ which may signify a decrease of c. 4-8C in mean annual temperature. In the pollen diagram *Pterocarya* temporarily disappears. The oxygen isotope curve then rises again to the mean value for the interglacial (ca. -9.2‰). The record ceases before the decline in $\delta^{18}O$ values, indicative of glacial temperatures, is recorded. A general decline in carbonate content, mainly in the uppermost sediment (above 9.5 m), suggests increased instability in the catchment which lead to inwash of detrital sediments.

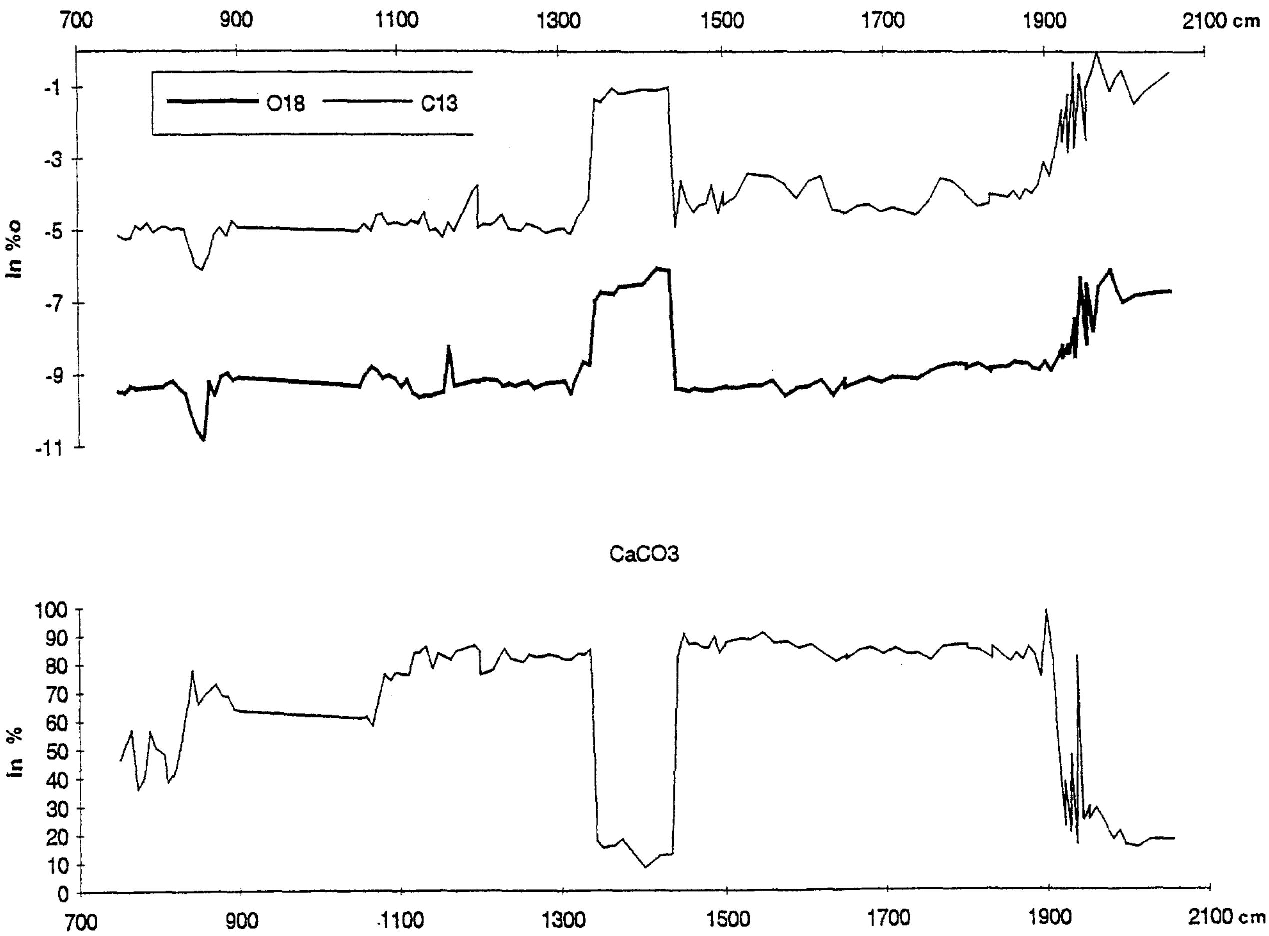

Fig. 10. Curves for ^{18}O and CO^{13}, and calcium carbonate content as a percentage of dry weight, core SM8 (La Côte)

Between 14.4 and 13.4 m depth, the isotope curve is interrupted by an abrupt event; ^{18}O increases by ca. 3‰ and the carbonate content decreases to ca. 15%. The fact that both curves change without any transitional stage

In its main characteristics, the ^{13}C curve runs similarly to the ^{18}O curve. Below 19 m and between 14.4 and 13.3 m, a marked change in $\delta^{13}C$ values points to inwashed detrital carbonate. Elsewhere, $\delta^{13}C$ values are rather low (- 4.5‰ on average) which suggests that equilibration was not established with atmospheric CO_2. It is possible that the residence time of the lake water was short and, furthermore, it is probable that, in general, the ^{13}C curve is largely reflecting the biological activity in the water body. Thus, the behaviour of the curve between 13.3 and 7.5 m may be accounted for by fluctuations in the bioproductivity of aquatic plants. The relatively high $\delta^{13}C$ values in the interval 13.3 and 10.2 m suggests greatly increased productivity which, in agreement with both the $\delta^{18}O$ curve and the pollen record, is indicative of favourable climatic conditions. As in the case of the $\delta^{18}O$ curve, more negative $\delta^{13}C$ values at about 9.5 m depth, suggest climatic deterioration which had the effect of reducing the bioproductivity in the submersed aquatics.

Comparison with other European sequences

This series of corings reveal interglacial vegetation dynamics that are particularly well developed in the La Côte profile (La Côte Interglacial). The great abundance of *Pterocarya* in SM8-15 and SM14/15-9) is a distinctive feature allowing correlation with the typical Holsteinian Interglacial from Northern Germany which is characterized by the presence of *Pterocarya* in its upper part. During both the Holsteinian and La Côte Interglacials, *Buxus, Taxus* and *Vitis* played a notable role, whereas *Carpinus* did not expand.

There are, however, differences in the vegetation history of the *locus typicus* and the Val-de-Lans sequences, the most striking being the scarcity of *Fagus* and the reduced role played by *Pterocarya,* even when at its optimum, in the Holsteinian sequence. Fortunately, two sites in the Alps which are in rather similar settings to those from Vercors, have provided pollen diagrams attributed to the Holsteinian, namely Samerberg 2 in Bavaria (Grüger 1983) and Thalgut in the Aar valley (Welten 1988). At Samerberg and Thalgut, the first *Picea* expansion is recorded prior to the expansion of mesic trees. This does not occur at La Côte although at that site the *Picea* curve starts very early. Both at Samerberg and at La Côte, *Taxus* achieved a maximum during the expansion phase of *Abies*, but the major expansion phases of *Buxus* and *Fagus* are recorded later than at La Côte. These differences do not necessarily imply that the Interglacial sequences are not contemporaneous; they may be accounted for by a vegetation differentiation related to migration paths and local conditions. This is not surprising in view of the even greater regional differences during the present interglacial, i.e. the Holocene.

Samerberg, Thalgut and Val-de-Lans are therefore good reference sites for the definition of an alpine facies of the Holsteinian Interglacial. However, the question arises about the correlation with the long Swiss sequence from Meikirch (Welten 1982a, b, 1988) which has long been the only Holsteinian reference site in the Alps. At that site, two interglacials are superimposed, separated by a thick sediment layer indicative of a glacial. The pollen assemblages from the upper interglacial are typical of the Eemian. The lower interglacial, also subdivided by a short cold episode, had been assigned to the Holsteinian, i.e. Holstein I and Holstein II *sensu* Welten. This is in agreement with the sub-division of the Quaternary by Penck and Brückner (1901-1909), since it underlies the glacial that preceded the Eemian. It seems impossible, however, to correlate the pollen sequences from the Thalgut Interglacial (identified as contemporaneous with the Holsteinian) with those of the Holsteinian *sensu* Welten from Meikirch (which may be more appropriately referred to as the Meikirch Interglacial).

Two hypotheses may be put forward to explain this difference. In the Meikirch sequence, a long sediment hiatus brings close together a new ante-Holsteinian Interglacial and the glacial period prior to the Eemian, thus obliterating the antepenultimate temperate cycle corresponding to the Holsteinian. An alternative interpretation is that the Meikirch sequence is really continuous, and the lower interglacial is thus younger than the Thalgut Holsteinian.

We prefer the second hypothesis because it is consistent with the modern concept of the Quaternary derived from the study of deep sea cores and from the astronomical theory of climate cycles corroborated by the existence during the lower Pleistocene of a greater number of alternating glacial/interglacial episodes than proposed by Penck and Brückner (1901-1909). Moreover, this hypothesis is in agreement with numerous German studies in which interglacial episodes are described between the Eemian and the Holsteinian (Erd 1970, 1973; Menke 1980; Menke and Behre 1973; Urban 1991).

It is not easy to establish a synthetic stratigraphical scheme for regions such as the Alps where glacial erosion may have obliterated many sedimentary episodes. On the other hand, ancient crater lakes constitute suitable sites for continuous sedimentation. Although not fully published, the long pollen sequences obtained from the Velay maars infillings (Reille and Beaulieu 1990; Beaulieu and Reille 1992; Beaulieu and Reille, in press) shed new light on the Middle Pleistocene biostratigraphy. The lower interglacial of the long Praclaux sequence (Praclaux Interglacial) (Reille and Beaulieu, manuscript submitted) closely resembles that of La Côte and Samerberg. The modest pollen values of *Pterocarya* can easily be explained by the unfavourable conditions provided by a volcanic region for a calcicolous species. An interglacial sequence overlying the Praclaux Interglacial (followed by stadials and two interstadials with dominant *Picea*) has proved to be older than the local paratype of the Eemian Interglacial, i.e. the Ribains Interglacial (Beaulieu and Reille 1992). Correlation with the long sequence from the nearby Lac du Bouchet also suggests that another interglacial (Bouchet Interglacial) took place between the Holsteinian and the Eemian, so that the Praclaux/La Côte/Holstein interglacial period must be represented by the third interglacial before the Eemian, and should therefore be contemporaneous with isotopic stage 11. This hypothesis is discussed in more detail in Beaulieu and Reille (1994). Such an hypothesis would explain (1) the great changes which have taken place in Val-de-Lans whereby a closed lake basin has evolved into the present valley which drains to the north and the south and (2) the deep erosion of the Pompillon formation and the strong pedogenesis of its surface (decalcified to over 8 m in SM10) where artefacts from the lower Palaeolithic were found.

Lastly, the Lolette I and II Interstadials, characterized by a dominant *Picea* forest, have good equivalents both at Praclaux (Jagonas Interstadials) and at Samerberg 2 (pollen zones 7 and 9). This further supports dating the three sequences to the same period. Comparisons can also be made with the Holsteinian and the post-Holsteinian episodes, Hoogeven and Bantega, described in the Netherlands by Zagwijn (1973).

Conclusions

The soft sediments accumulated on the Lans-en-Vercors plateau were first interpreted, on the basis of surface observations, as a glacio-lacustrine series of Rissian age (Malenfant and Monjuvent 1978). Several corings have shown the greater complexity of the so-called Pompillon formation. Palynological results enable the lower part of the lacustrine infilling to be attributed to a glacial period and to correlate the succeeding interval, referred to here as the La Côte Interglacial, with the Holsteinian. An erosional phase may have occurred between the interglacial deposits and the upper part of the sequence which was deposited under cold climatic conditions and is considered to be older than the last interglacial. This part of the sequence cannot be dated precisely; neither can the thick Isère ice-sheet that obstructed the Furon valley and resulted in the ice-rafted allochthonous crystalline blocks and pebbles that are included in the Villard-de-Lans cone. The $\delta^{18}O$ record indicates slight climatic oscillations during the La Côte Interglacial. The late phase, with abundant *Pterocarya*, appears to represent a slightly warmer period.

The Pompillon formation occupies a high valley separated from the extensive lower Dauphiné Pleistocene series. This makes it difficult to establish regional stratigraphical correlations. The Pompillon pollen assemblages, however, provide very favourable material for biostratigraphic and bioclimatic correlations at the European scale.

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References

Beaulieu JL de, Monjuvent G (1979) Mise en évidence de dépôts de type interglaciaire ancien sur le plateau de Lans-en-Vercors (Isère, France). C R Acad Sci Paris 288, sér D: 1651-1654

Beaulieu JL de, Monjuvent G (1985) Données actuelles sur la formation interglaciaire de Pompillon (Pléistocène moyen), Val-de-Lans en Vercors (Isère, France). Bull Assoc Fr Etud Quartaire 2-3: 75-83

Beaulieu JL de, Reille M (1992) Long Pleistocene pollen sequences from the Velay Plateau (Massif Central, France). Veget Hist Archaeobot 1: 233-242

Beaulieu JL de, Reille M (1994) Pollen records from the Velay craters: a review and correlation of the Holsteinian Interglacial with isotopic stage 11. Meded Rijks Geol Dienst (in press)

Craig H (1977) Isotopic standard for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxyde. Geochim Cosmochim Acta 12: 133-149

Erd K (1970) Pollen-analytical classification of the Middle Pleistocene in the German Democratic Republic. Palaeogeogr Palaeoclimatol Palaeoecol 8: 129-145

Erd K (1973) Vegetationsentwicklung und Biostratigraphie der Dömnitz-Warmzeit (Fuhne/Saale 1) im Profil von Pritzwalk/ Prignitz. Abh Zentral Geol Inst, Berlin 18: 9-48

Grüger E (1983) Untersuchungen zur Gliederung und Vegetationsgeschichte des Mittelpleistozäns am Samerberg in Oberbayern. Geol Bavarica 84: 21-40

Malenfant M, Monjuvent G (1978) Les gisements du Paléolithique inférieur du Val-de-Lans (Vercors, Isère) et leur cadre morphogéologique. Géol Alpine 54: 125-146

Menke B (1980) Wacken, Elster-Glazial, marines Holstein-Interglazial und Wacken-Warmzeit. In: Stremme HE, Menke B (eds) Quartär-Exkursionen in Schelswig-Holstein, vol 5. Geologisches Landesamt Schleswig-Holstein, Kiel, pp 26-35

Menke B, Behre KE (1973) History of vegetation and biostratigraphy. Eiszeitalter G 23/24: 251-267

Penck A, Brückner E (1901-1909) Die Alpen im Eiszeitalter. Publisher, Leipzig

Reille M, Beaulieu JL de (1989) The Velay maars (Massif Central, France): key-sites for the Middle and Upper Pleistocene pollen sequences. In: Rose J, Schlüchter C (eds) Quaternary type sections: imagination or reality? Balkema, Rotterdam, pp 79-89

Reille M, Beaulieu JL de (1989) Pollen analysis of lake sequences obtained in two maars of the Massif Central: Lac du Bouchet and Praclau. Abstracts, EVG Meeting, Terra, vol 1, no. 1, p 225

Reille M, Beaulieu JL de (1990) Pollen analysis of a long upper Pleistocene continental sequence in a Velay maar (Massif Central, France). Palaeogeogr Palaeoclimatol Palaeoecol 80: 35-48

Siegenthaler U and Eicher U (1986) Stable oxygen and carbon isotope analyses. In: Berglund, BE (ed) Handbook of Holocene palaeoecology and palaeohydrology. Wiley, Chichester, pp 407-422

Urban B (1991) Zusammenfassung biostratigraphischer Ergebnisse holstein- und saalezeitlicher Vorkommen im Tagebau Schöningen, Ldkrs. Helmstedt. Sonderveröffentlichungen, Geologisches Institut der Universität zu Köln 82 (Festschrift Kar Brunnacker): 329-342

Welten M (1982a) Stand der palynologischen Quartärforschung am schweizerischen Nordalpinrand. Geogr Helv 2: 75-83

Welten M (1982b) Pollenanalytische Untersuchungen im Jüngern Quartär des nördlichen Alpen-Vorlandes der Schweiz. Beitr Geol Karte Schweiz 156: 1-174

Welten M (1988) Neue pollenanalytische Ergebnisse über das Jüngere Quartär des nördlichen Alpenvorlandes der Schweiz (Mittel- und Jungplaistozän). Beitr Geol Karte Schweiz 162: 1-40

Zagwijn WH (1973) Pollenanalytical studies of Holsteinian and Saalian beds in the northern Netherlands. Meded Rijks Geol Dienst NS 24: 139-156

Zagwijn WH (1989) Vegetation and climate during warmer intervals in the Late Pleistocene of western and central Europe. Quat Int 3/4: 57-67